

# Nanoenabled Directions for N/MEMS



Dennis Polla  
DARPA MTO

6 March 2007  
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# A MTO Nanotechnology Vision



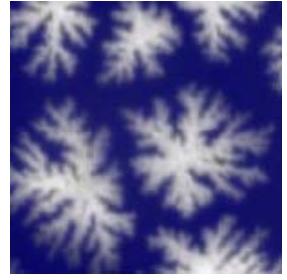
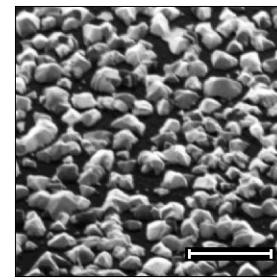
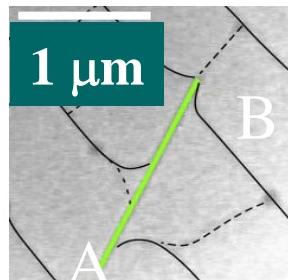
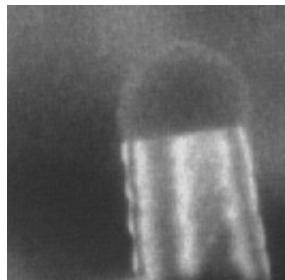
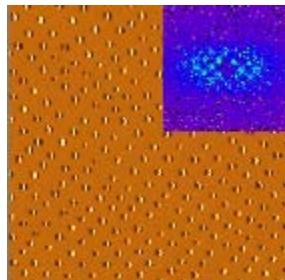
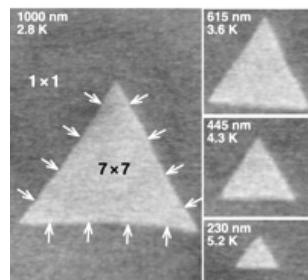
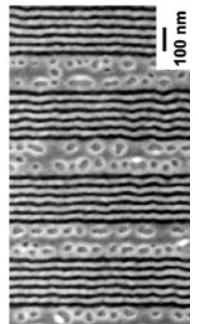
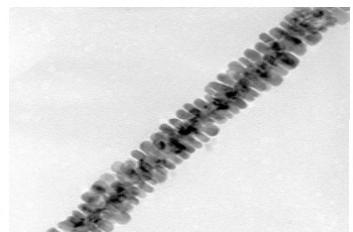
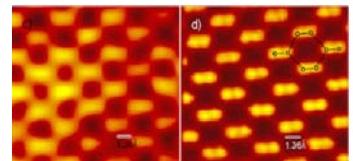
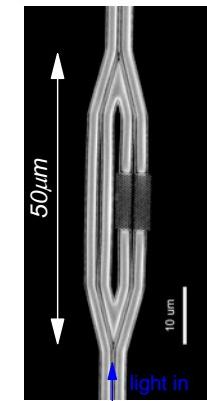
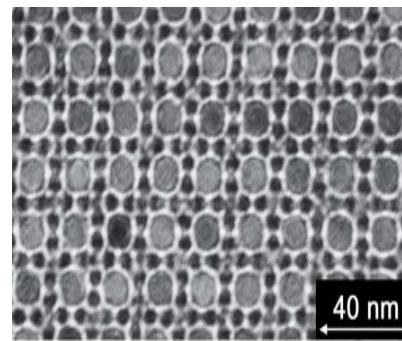
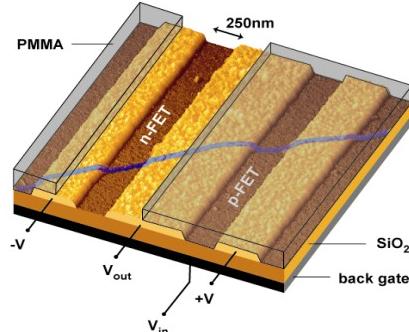
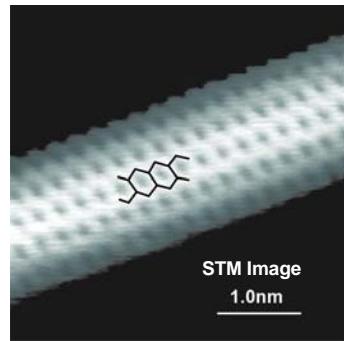
## Nanotechnology Enabled Opportunities

- **Chip-Scale Microfluidic Analyzers**
- **Nanosensors**
- **Nanowires for Sensors and Electronics**

# Nanotechnology and N/MEMS

## Two key themes:

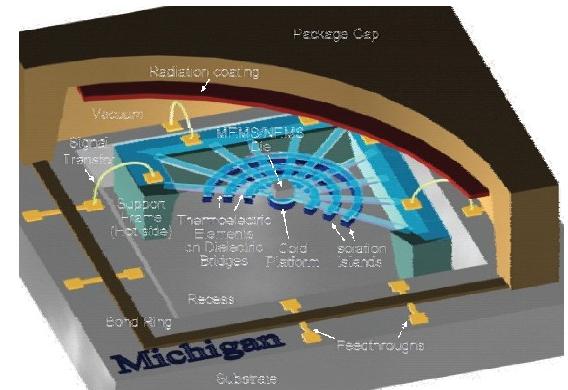
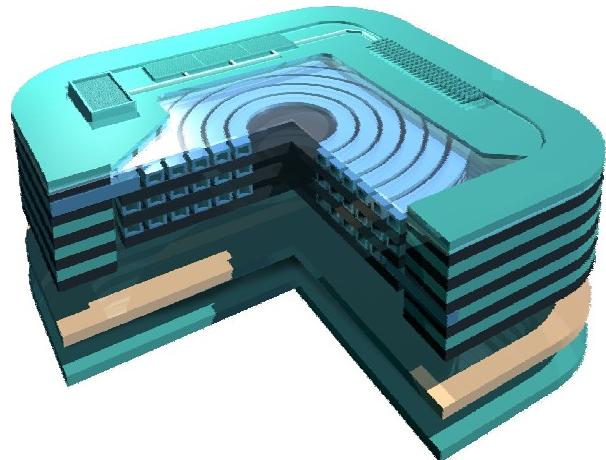
- Nanotechnology enables new applications and drives performance
- Nanotechnology is emerging as a key aspect of integrated microsystems



Images courtesy of Philip Wong, Stanford University

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# N/MEMS Program Examples



## Micro Gas Analyzers

- CNT Preconcentrators
- Nanomechanical Sensors
- CNT Detectors
- Functionalized Chemiresistors

## N/MEMS S&T Fundamentals

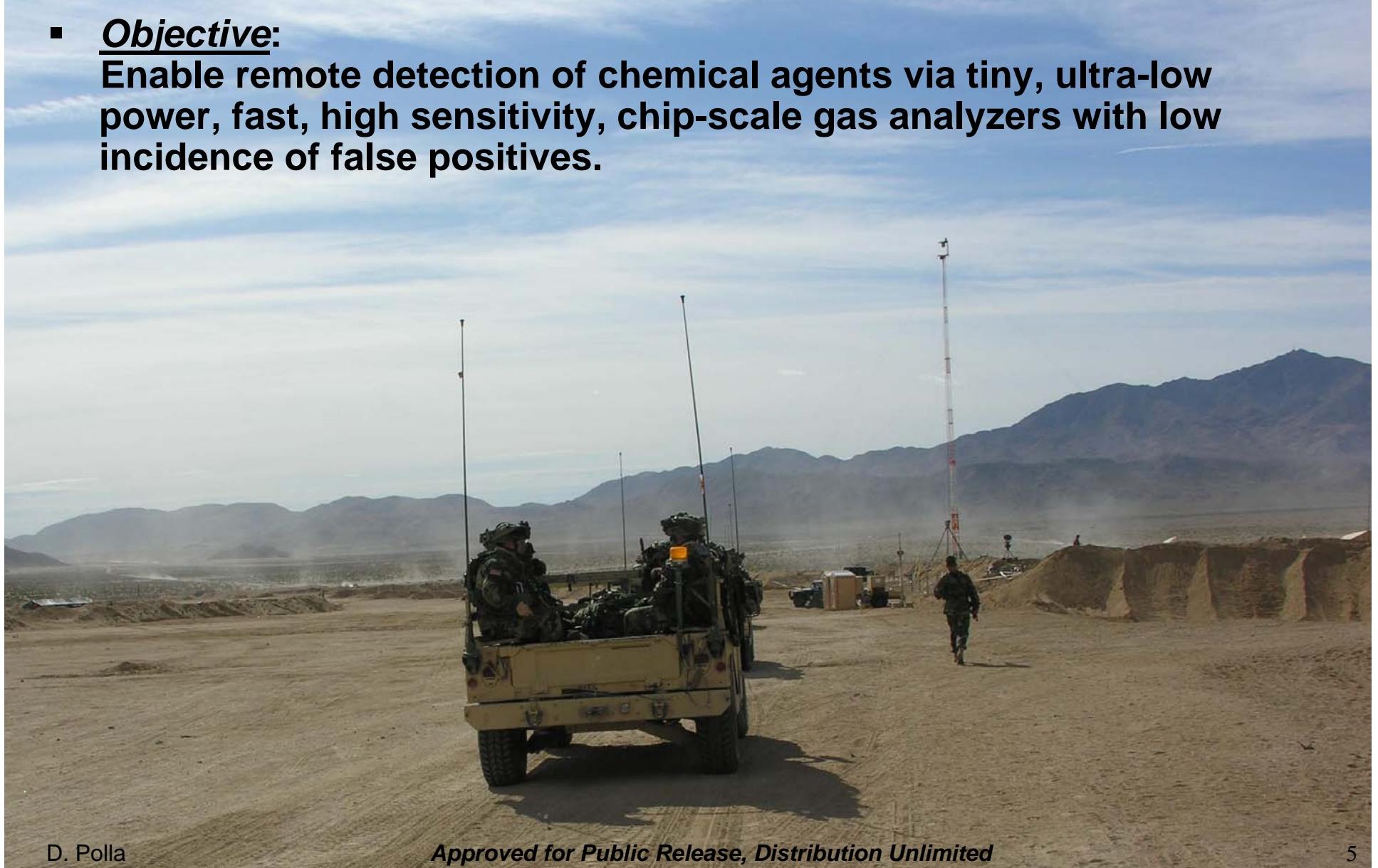
- CNT Sensors
- NEMS Biosensors
- Nanoresonators
- Reconfigurable Nanoelectronics

## Micro Cryogenic Coolers

- Thermal nanostructures
- Nanoenabled cryogenic cooling

- **Objective:**

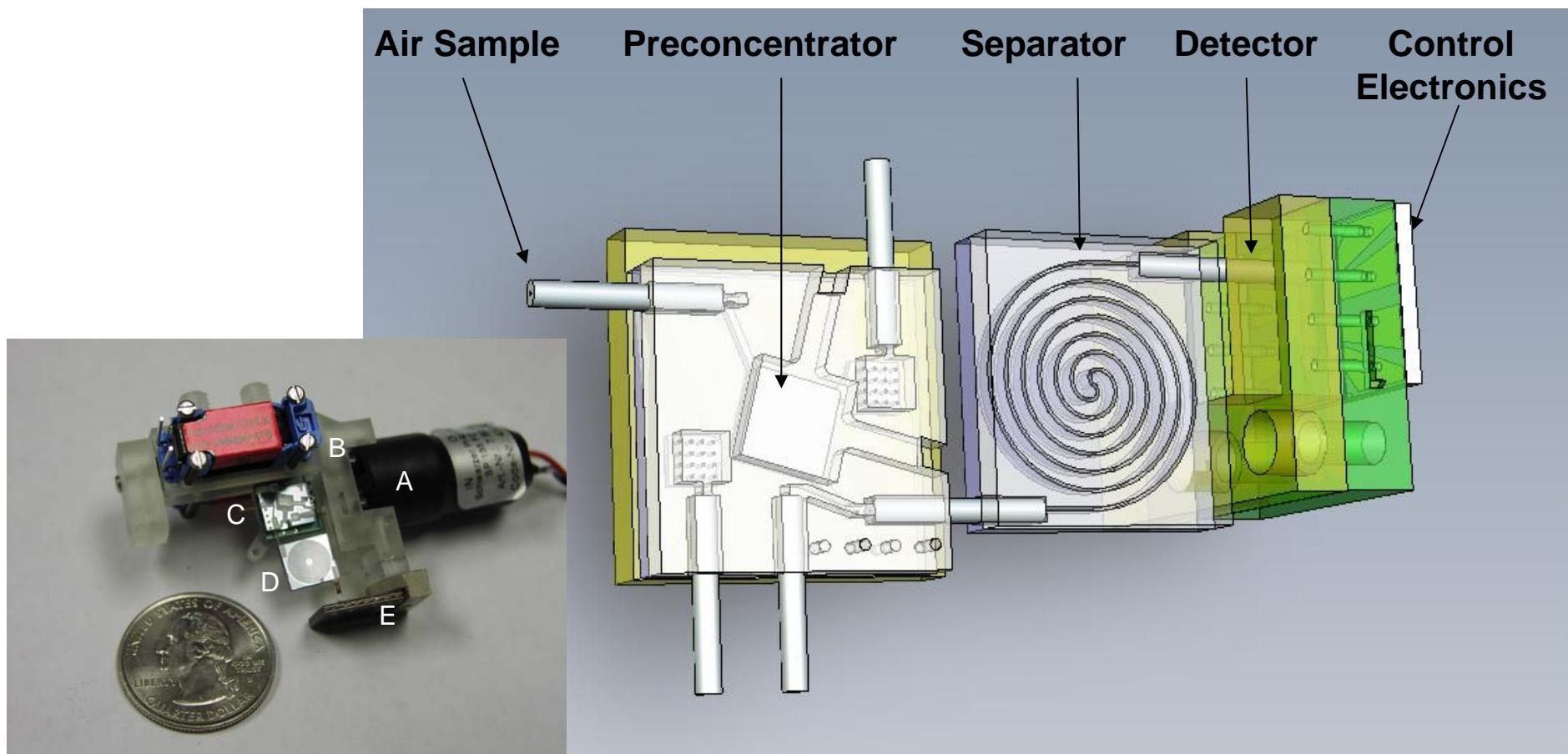
Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.



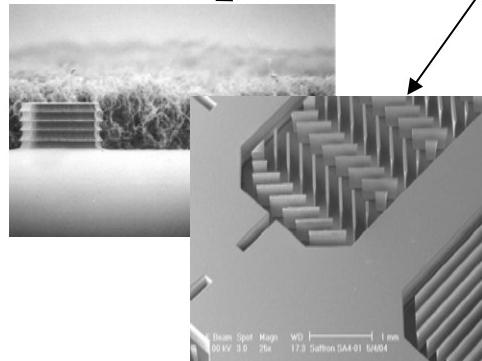
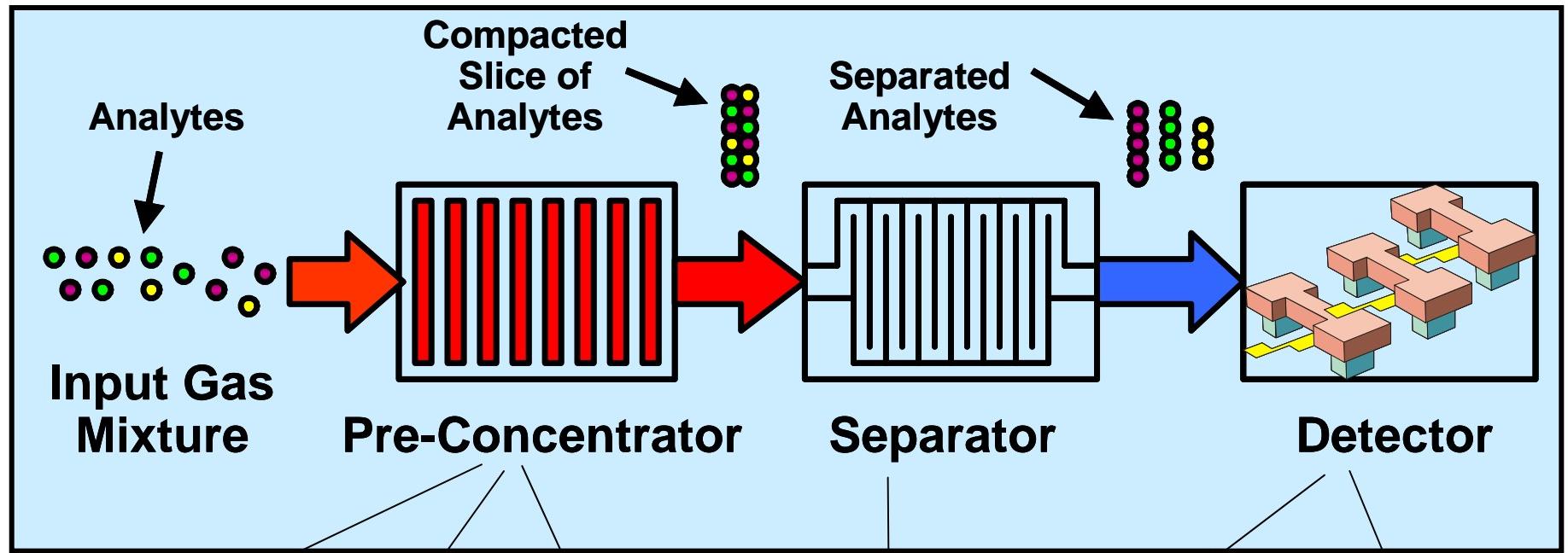
# Sugar Cube – Size Instrument

- **Objective:**

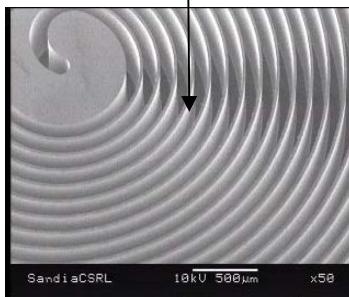
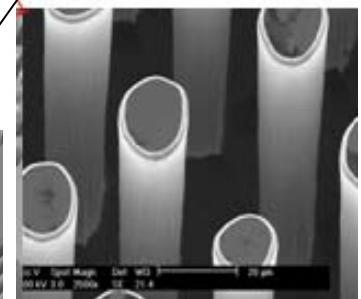
**Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.**



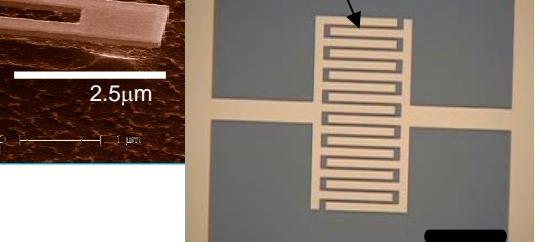
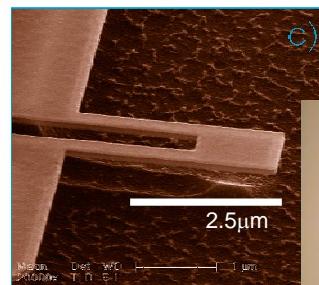
# Integrated N/MEMS Components



- Very high effective surface area
- Chemical functionalization

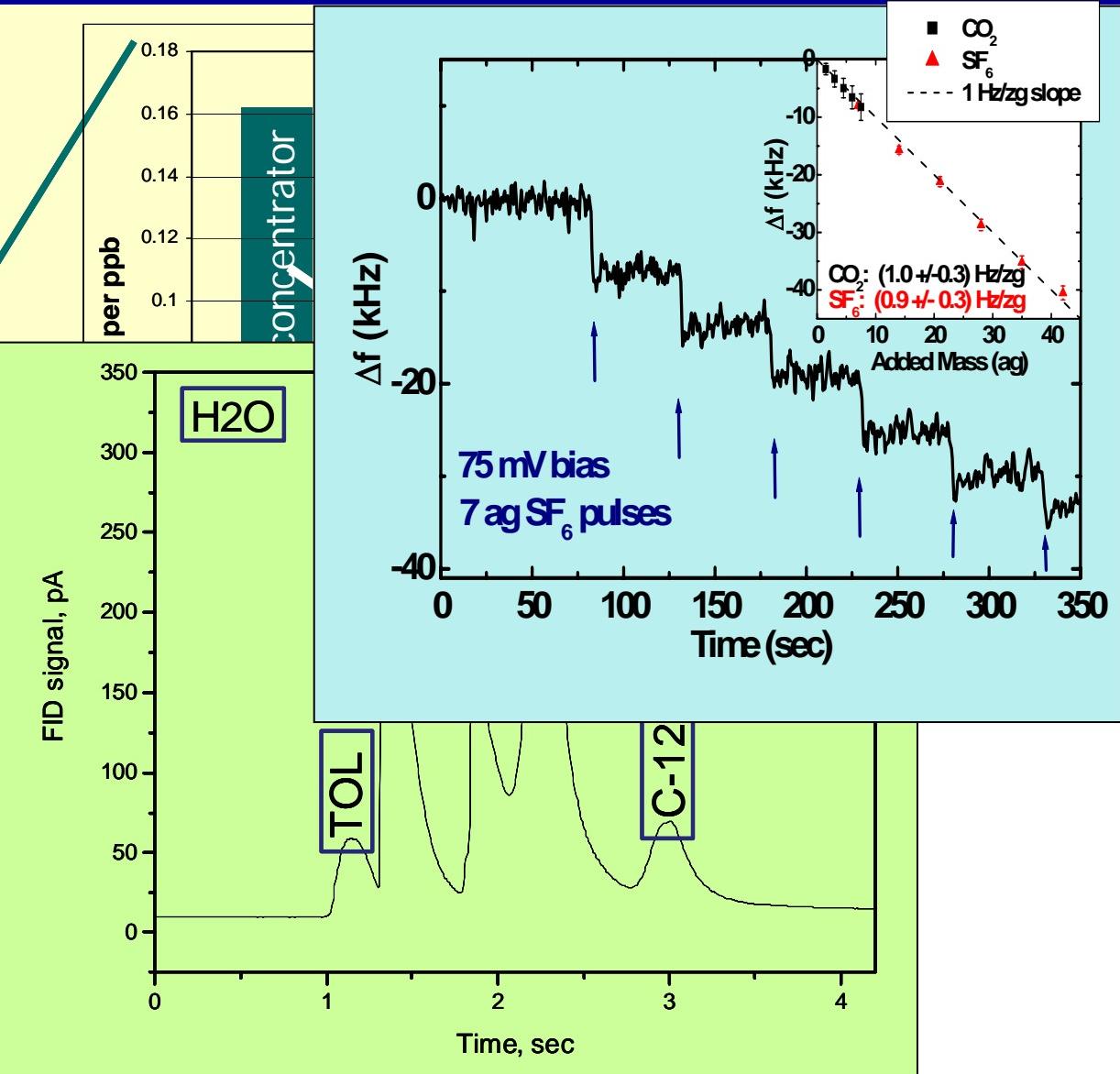
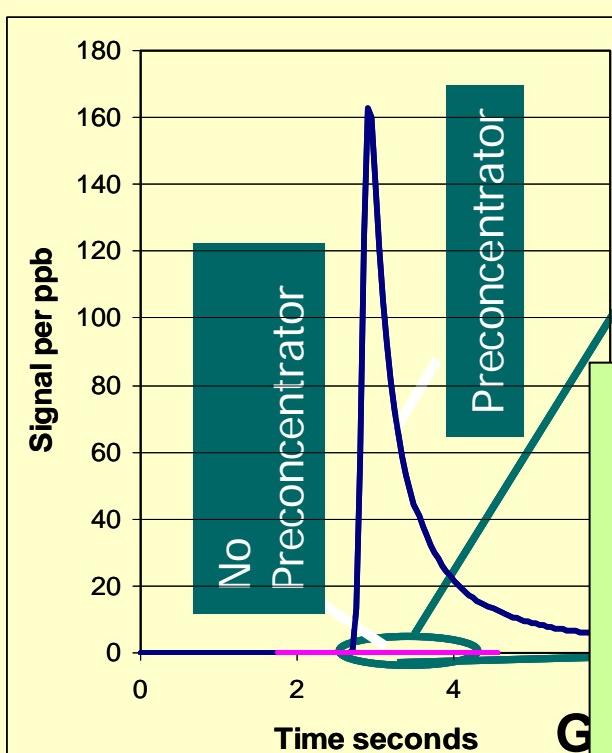


- DRIE
- Chemical polishing



- Low proff-mass
- Chemical functionalization

# Enhancement of Performance



## Nanotechnology Lessons Learned:

- Nanotechnology and MEMS (a terrific combination!)

Size:  $40,500 \text{ cm}^3$   $2 \text{ cm}^3$

- Nanotechnology enables systems with unprecedented performance:

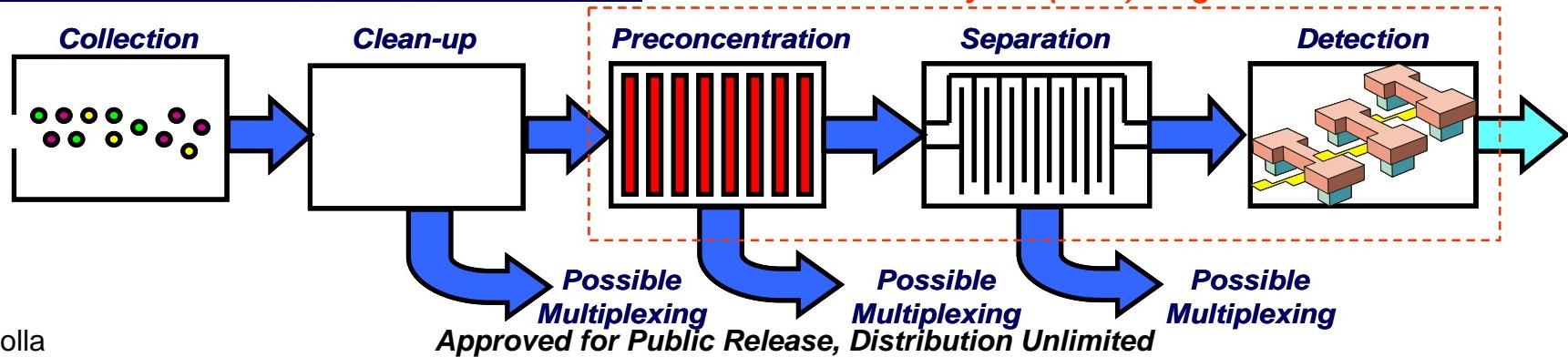
Sensitivity: 1 ppb  $1,000X$   $< 1 \text{ ppt}$

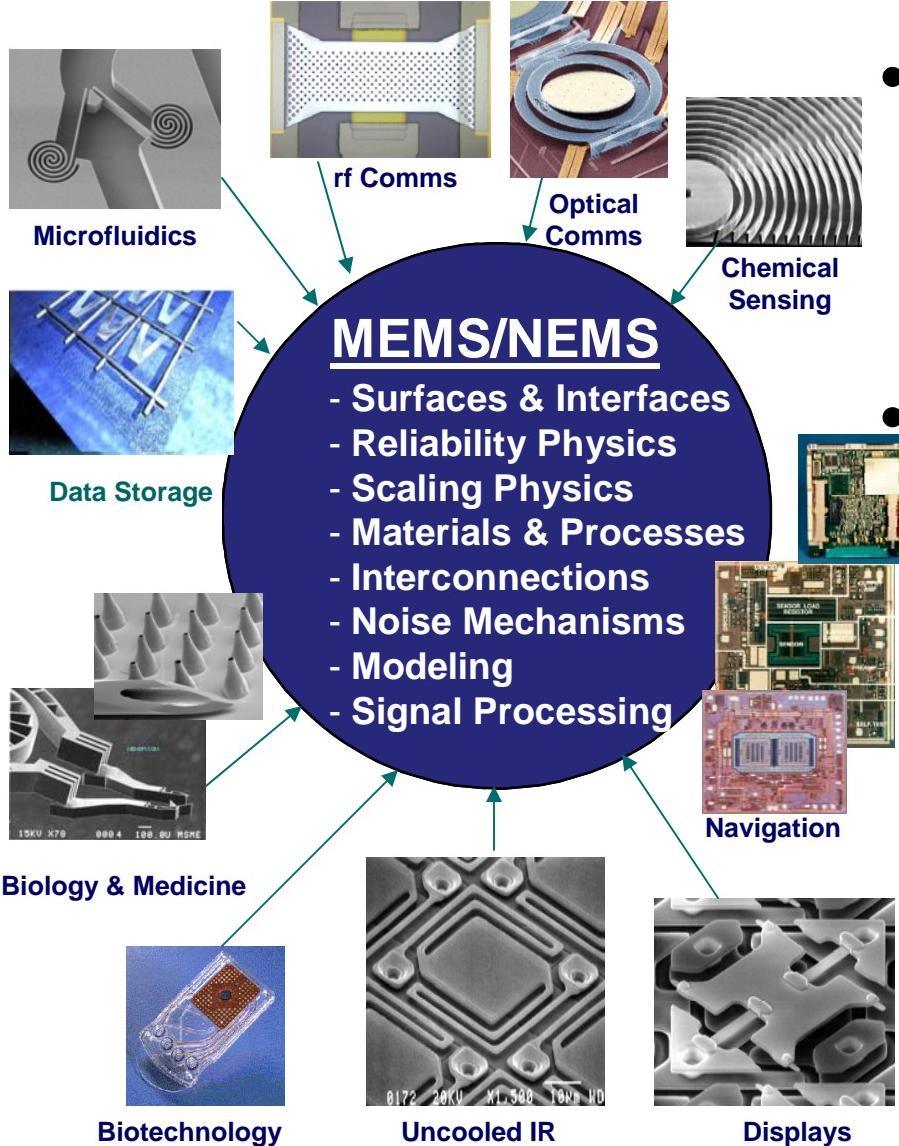
Analysis time: 15 min  $225X$  4 s

Energy per analysis:  $10^4 \text{ J}$   $10,000X$  1 J

## Nanotechnology Opportunity

### Micro Gas Analyzers (MGA) Program





- **Goal:**

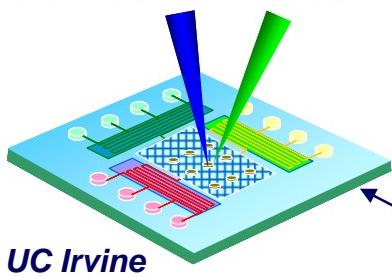
- Support basic research of importance to DoD in N/MEMS

- **Technical Challenges**

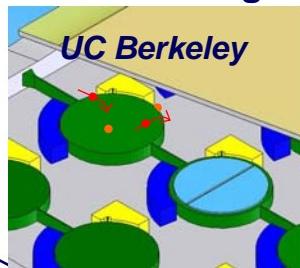
- Failure Mechanisms and physics
- New materials and processes
- Scaling laws in multiple domains
- Interfaces and interconnects between the macro-micro-nano worlds.

# N/MEMS S&T Fundamentals

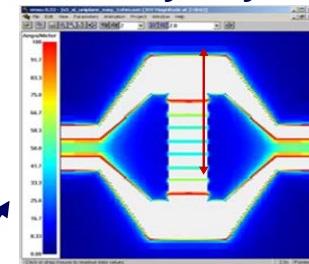
## Microfluidic Processors



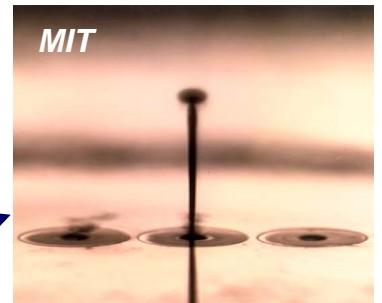
## RF Scaling



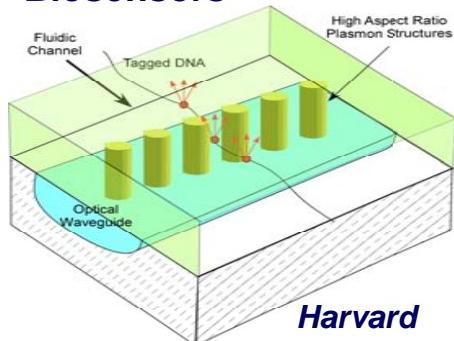
## Reliability Physics



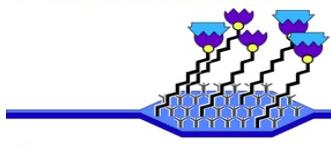
## Non-lithographic Fabrication



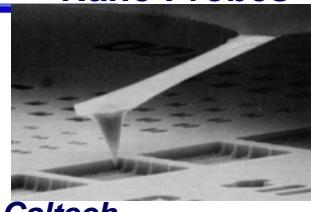
## Biosensors



## Functionalized Surfaces



## Nano Probes

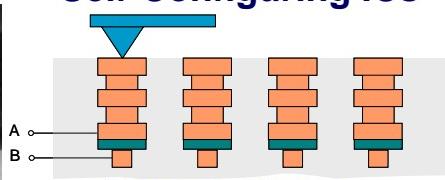


## MEMS/NEMS

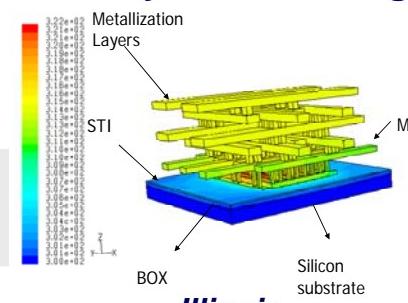
- Surfaces
- Interfaces
- Reliability
- Scaling
- Materials
- Fabrication
- Modeling
- Nanostructures



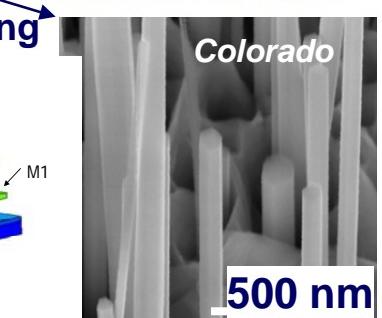
## Self-Configuring ICs



## Multi-Physics Modeling



## Nanowire Sensors





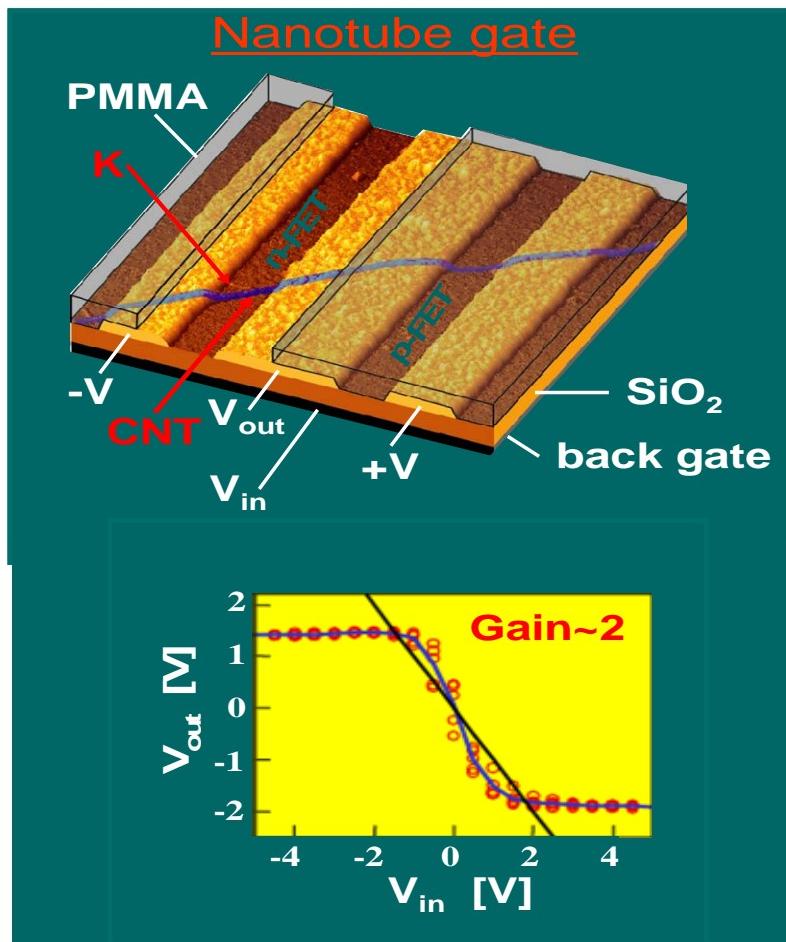
# Nanotechnology Vision



*Six Nanoenabled Opportunities*

- 1. Nanoenabled Electronics**
- 2. Nanoenabled Informatics**
- 3. Nanoenabled Biotechnology**
- 4. Nanoenabled Plasmonics and Photonics**
- 5. Nanoenabled Sensors**
- 6. Nanoenabled Energy**

## Nanowire Electronics

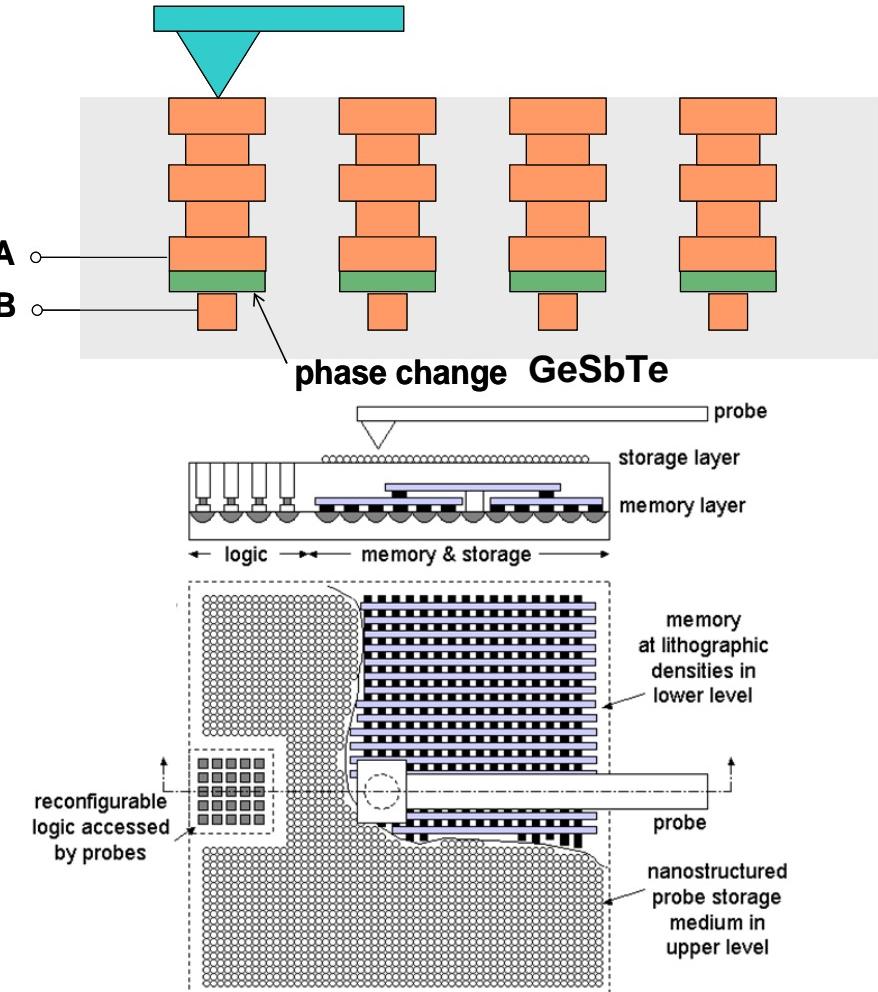


### Key Challenges

- Controlled Growth
- Selective Placement
- Interconnections

D. Polla

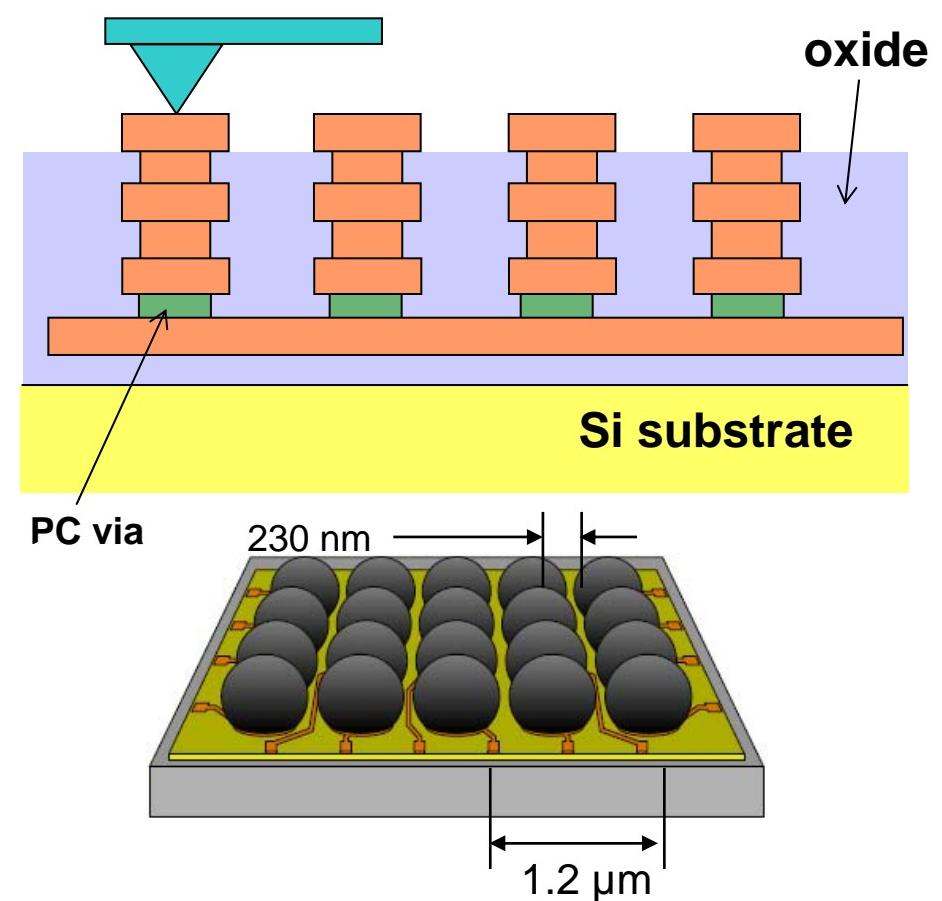
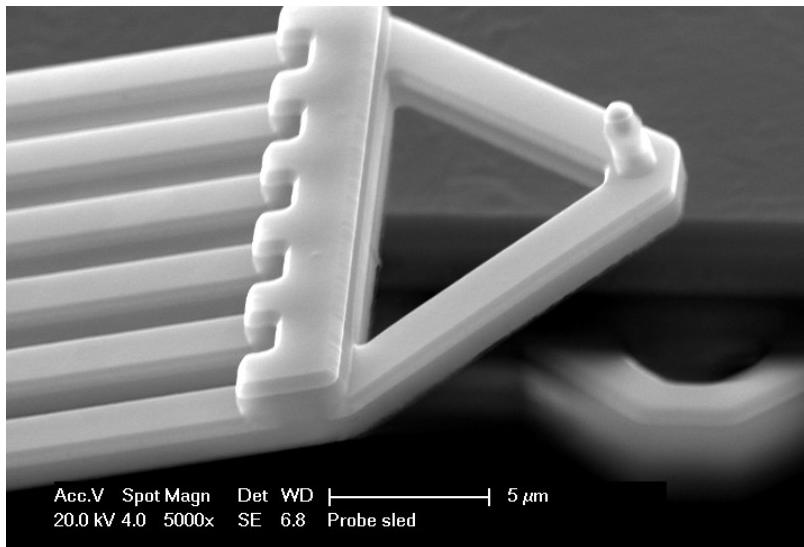
## Self-Configuring Electronics



T. Schlesinger, DARPA  
N/MEMS S&TFundamentals, CMU.

# Self-Configuring ICs

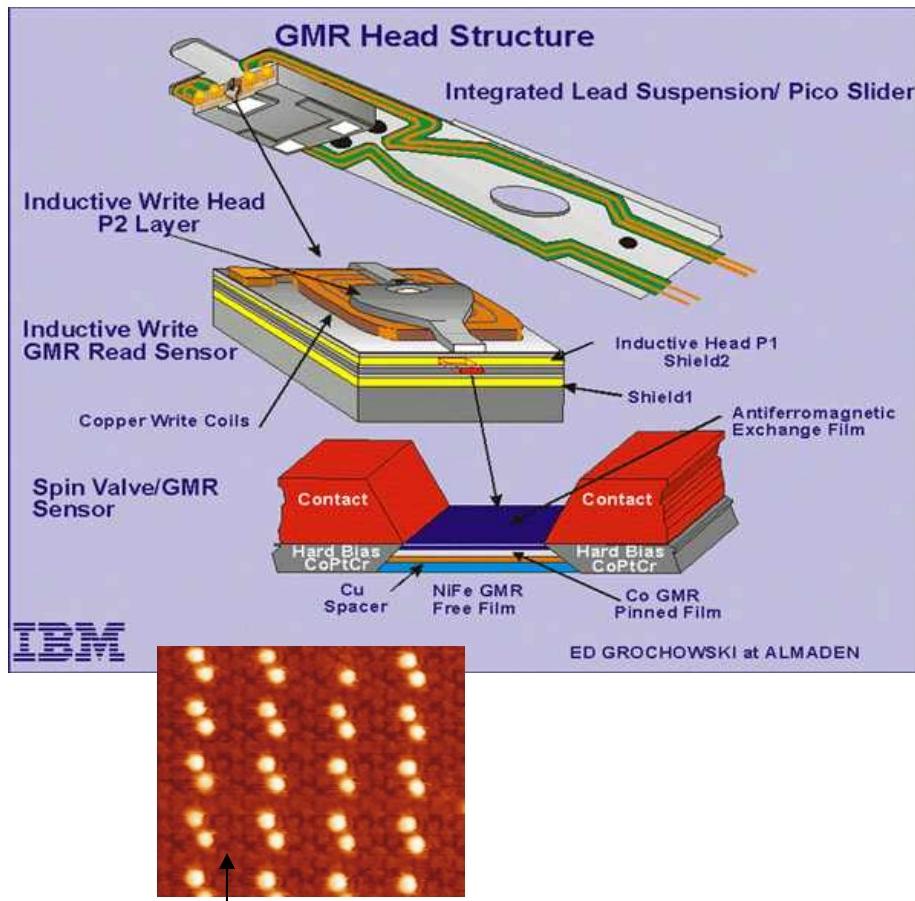
- NEMS Thermal Actuators
- Designed-in stress gradient
- 3 μm post, 230 nm tip area



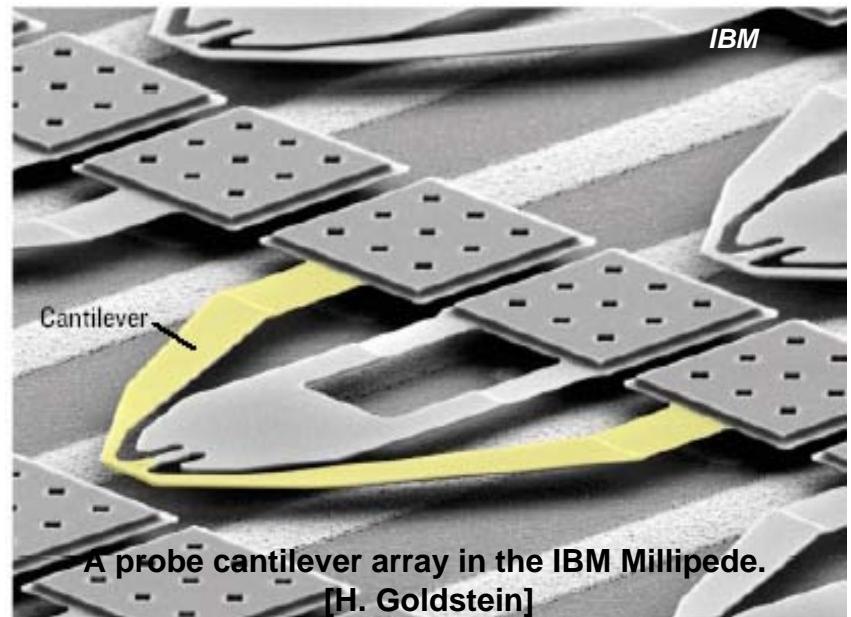
***Imagine... Dynamically changing the basic function of an electronic chip according to current need.***

## Storage Media

**Feature size reductions dramatically increase the capacity of storage media. Nanotechnology enables future optical and magnetic storage.**

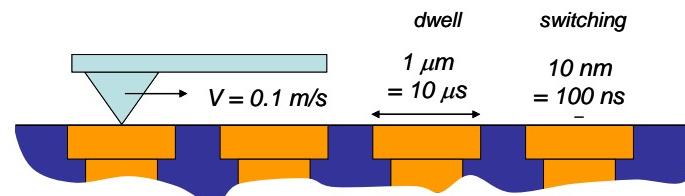


## Nanomechanical Memory



### Key Aspects

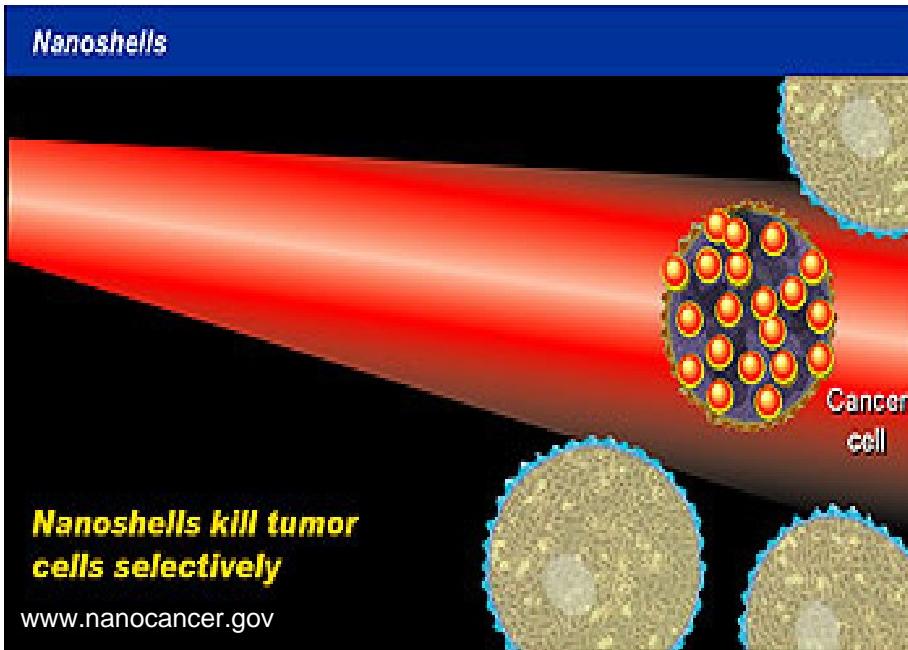
- MEMS probes used for media read/write
- 3 Tbits/inch<sup>2</sup> demonstrated



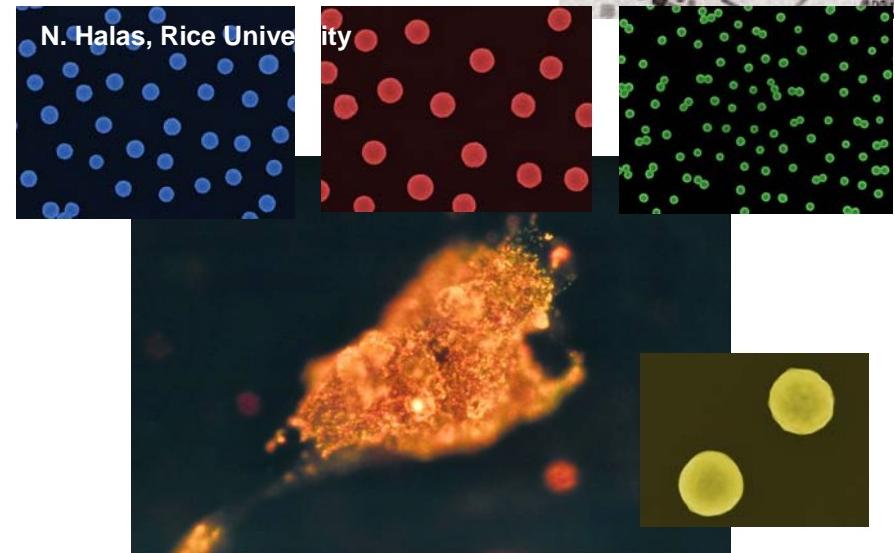
# Nanoenabled Biotechnology

## Medical Therapeutics / Drug Delivery

Therapeutic nanoparticles can be targeted to specific biological sites.

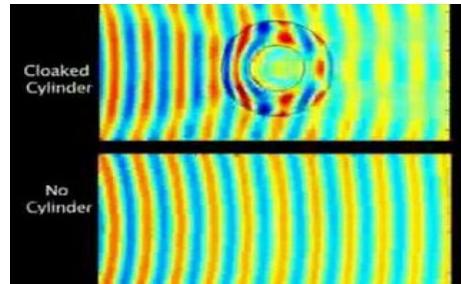
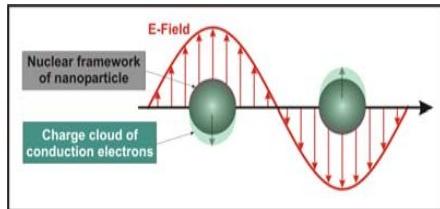
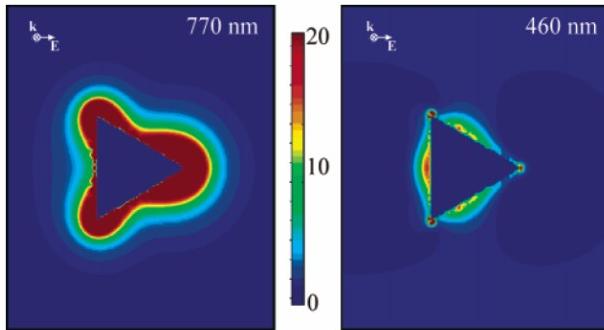


## Nanoparticles



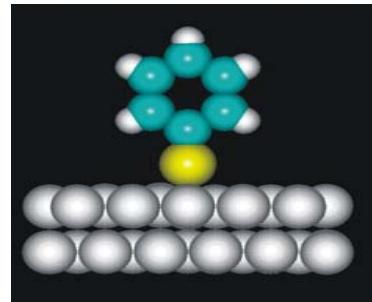
***Imagine... Site specific targeting of nerves with therapeutic nanoparticles that enhance sensory perception.***

## Plasmonics



## Key Challenges

- Control of EM-field Enhancement
- Materials properties

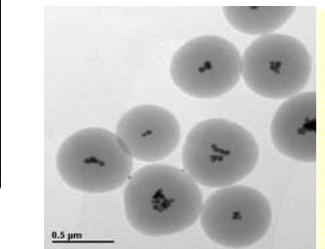
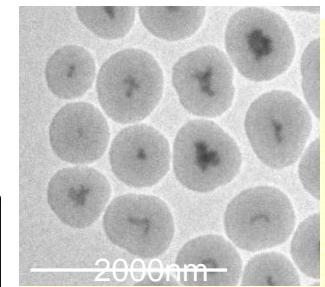
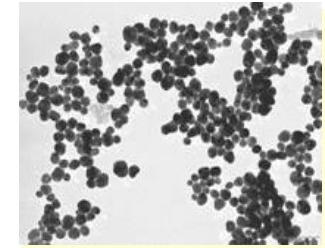
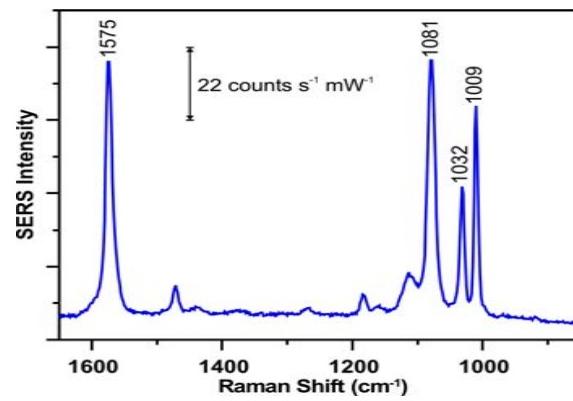


## SERS Nanosensors

**Basic physics and materials science associated with SERS nanoparticles as physical, chemical, and biological nanosensors**

### Spectral finger-printing

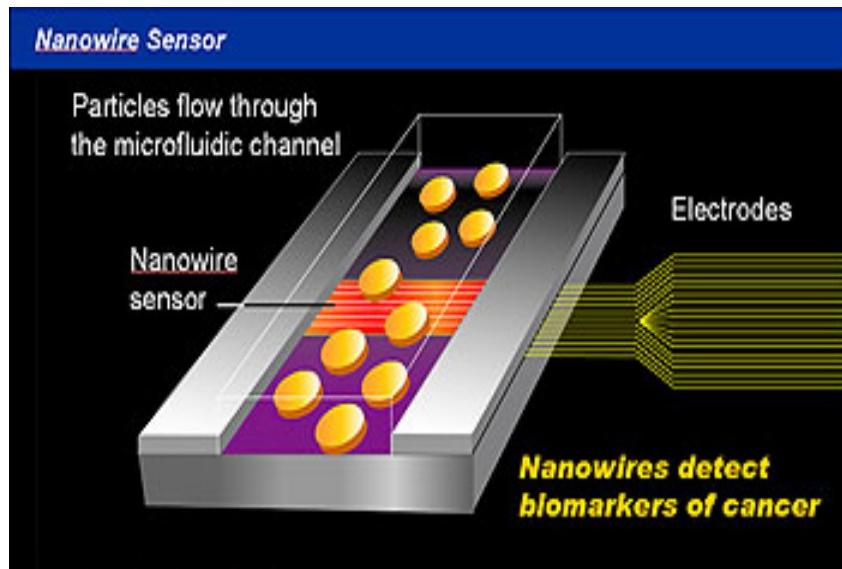
- sub-ppt sensitivity
- $P_D > 99.99\%$
- FAR  $< 1:10^9$
- Fast response  $< 1$  s



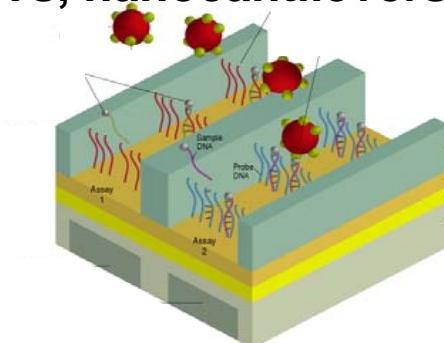
***Imagine... Nanosensors with ppq sensitivities and no false alarms.***

# Nanoenabled Sensors

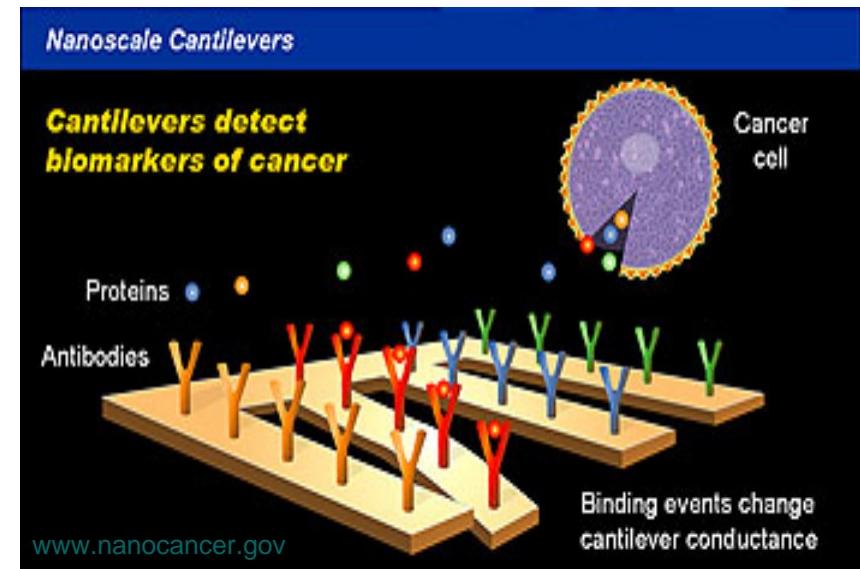
## Nanowire Sensors



- **Nanowires, CNTs, nanocantilevers, nanoparticles, quantum dots, nanoporous, magnetic materials**



## Nanomechanical Sensors

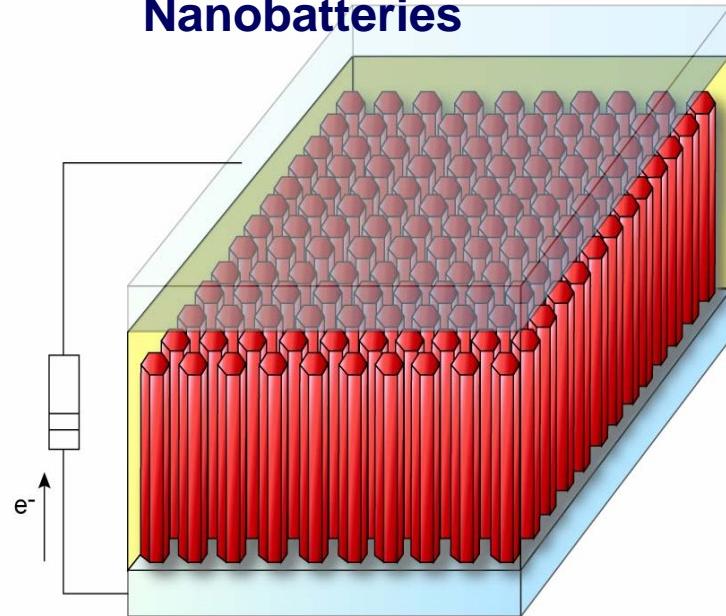


- **Application examples:**
  - Gas sensing
  - Protein/DNA detection
  - Particle detection
  - Chemical detection
  - Signal amplification (e.g.SPR)

**Imagine... Integrated multi-functional nanosensor modules capable of multiplexed bioanalysis and physical sensing.**

# Nanoenabled Energy

## Nanobatteries



ZhangP. Yang, U.C. Berkeley

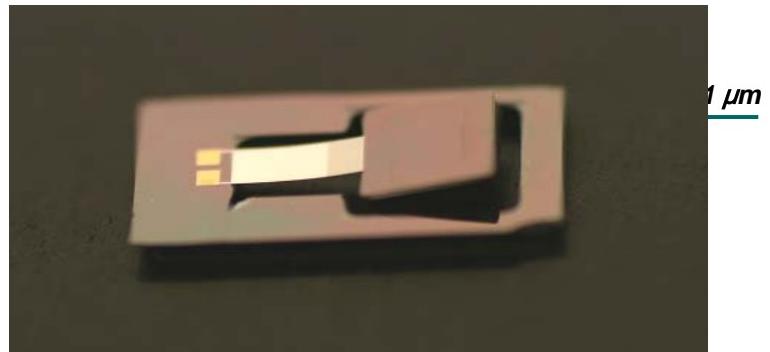


**Sandia National  
Laboratories Thermo-  
photovoltaic  
Power Converter**

## Piezoelectric Energy Scavengers



Zhang, Nano Letters, 3 (2004) 423-426.

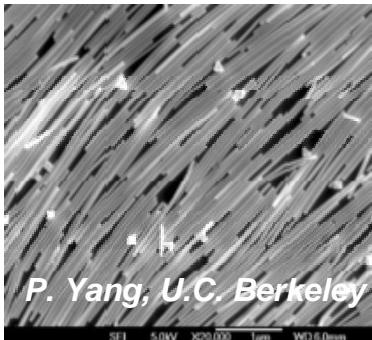


**Cornell Prototype MEMS Continuous-  
Mode Piezo-Cantilever Beta converter**

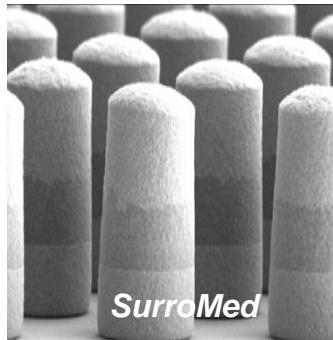
***Imagine... Never having to replace a battery.***



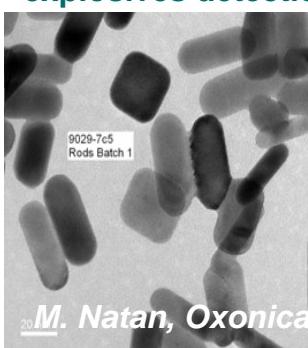
# Nanowires for Sensors & Electronics



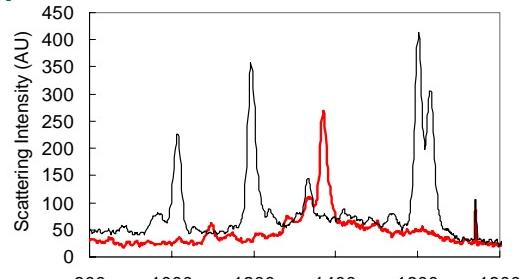
P. Yang, U.C. Berkeley  
Ag nanowires for explosives detection



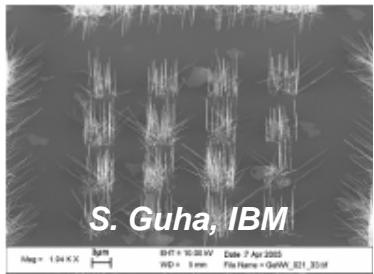
Encoded nanowires



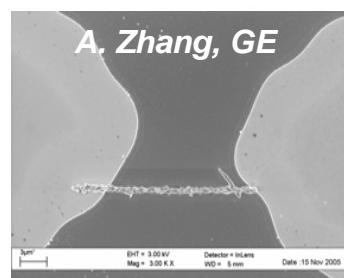
M. Natan, Oxonica



Au nanowires for multiplexed bioanalysis



S. Guha, IBM  
Vertical selective growth of Ge nanowires for sensor and electronics applications



A. Zhang, GE  
Assembled Co nanowire

- Goal:

- Develop new chemical, and biological nanosensors based on nanowires

- Applications

- All types of sensing
- Energy harvesting
- Thermal management
- New class of nanosensors for the detection of biochemical warfare agents.



# Lessons Learned



## What are the opportunities for nanotechnology?

1. Largest opportunities for nanotechnology are in enabling new systems
2. Look to nanotechnology to enable performance; not drive down cost.
3. Nanotechnology apps are best driven from top-down not bottom-up.
4. Multi-domain scaling is the key to performance-driven nanotechnology.
5. World competition is intense. Success in nanotechnology requires a vision, patience, and entrepreneurial spirit.



# Summary



**Many, many new challenges remain (Challenge = Opportunity)**

## Microfluidic Analyzers

- Preparation (nanostructures)**
- Preconcentration (nanochem)**
- Nanoanalytics**
- Nanodetectors (multiplexing)**

## SERS Nanosensors

- Enhancement Factor (EM)**
- Substrates**
- Geometries**
- Porous nanoparticles**

## Nanowires

- Nanosensors**
- Nanosolar cells**
- Nanoenergy scavenging**
- Thermal interfaces**



dpollo @ darpa.mil